WOODS HOLE OCEANOGRAPHIC INSTITUTION

REFERENCE NO. 65-62

OBSERVATION WINDOWS OF THE DEEP SUBMERSIBLE, *ALVIN*

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Woods Hole, Massachusetts

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by

James W. Mavor, Jr.

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TECHNICAL REPORT

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Approved for Distribution E E Hays

E. E. Hays, Chairman
Department of Applied Oceanography

ABSTRACT

The basis of the design of the *ALVIN* plexiglas windows is presented. The results of several tests of plexiglas windows are presented and discussed. It is concluded that the lapping of windows into their seats is unnecessary and that close fit is also not required. The *ALVIN* windows are conservative in design for an operating depth of 6000 feet. The use of a test window seat which does not simulate the hull strains is satisfactory for window test. It is recommended that the conical window seat be extended inward beyond the window to allow for normal elastic extrusion. Plexiglas windows are susceptible to collision damage due to brittleness and low strength of the material. An external rubber gasket was required to prevent low pressure leakage.

Windows have been considered a necessary part of manned submersible vehicles by most pioneers in the field. Only in the case of the large, high speed, military submarine which has claimed the lion's share of interest during this century have windows been considered operationally unnecessary. From the development of Beebe[1] and Barton[2] comes the use of the small quartz window. From Piccard's[3] work with bathyscaphes has grown an increasing confidence in methyl-methacrylate as manufactured under the trade names of Plexiglas and Lucite.

The oceanographic scientific community has been urging the development of windows for manned submersibles for some time. As a result we find increasing window area in the recently constructed vehicles. The *DENISE* of Costeau has two (2) inch diameter windows forward. *ALUMINAUT* has four four inch windows forward. *ALVIN* has four five inch diameter windows and one two inch window. The *"AUGUSTE PICCARD"* of Jacques Piccard has (40) windows. The submersibles presently under design and construction by private interests in this country and abroad make use of developments. There appear to be two channels available, one in which a few small windows can be used in conjuction with externally mounted optics to give a wide field of vision. The other leads ultimately to a pressure hull almost or completely made of a transparent material. Both avenues are worthy of development, one is primarily an optical problem, the other primarily a structural one. Let us explore the structural problem.

Many materials have exciting possibilities for use in pressure resistant components of manned submersibles. We find development of many of them under way. Generalized curves which compare materials with respect to hull weight for various depths have been published and while helpful in the promotion of basic research funding are of little value in the design of a particular submarine. The details create the real problems. Steel, of good ductility and fracture toughness is still the only proven basic pressure hull material. When plexiglas windows are used in a steel hull, it is discovered that the plexiglas, though a brittle material, is much more elastic than the steel and can thus be used in contact with the steel without fear of cracking in way of strain raisers. On the other hand, the large difference in modulus of elasticity requires that the steel shell be reinforced. The window does not support in the same manner as did the steel which it replaced.

The plexiglas windows of the deep diving submarine *ALVIN* were designed using Figure (1) representing the work of August Piccard. Spot No. 7 represents a conservative placement to assure failure at greater than 7500 psi. Point No. 5 and No. 6 are data points from WHOI full scale window tests. No. 5 is the initiation of plastic flow and No. 6 the highest pressure used in the test. It is noted that only two of Piccard's data points lie to the right of point No. 7 which cast some uncertainty into the picture. The domain below the lower curve represents elastic behavior and that above but below the upper curve, permanent deformation. Point No. 4 represented a failure of Piccard's test window seat rather than the window so that the upper curve apparently has

no meaning. Fig. 1 represented to the author's knowledge the only published test data on plexiglas windows. There was, however, some testing of models of the windows of the bathyscaphe *TRIESTE* performed at the Naval Electronics Laboratory, San Diego. Dr. Andreas Rechnitzer showed the author these models which had behaved satisfactorily to very high pressure.

After selection of the size and shape of the window, Fig. 2, the hull reinforcement was designed to suit. The goal of no stress substantially higher than the membrane stress in the unthickened shell was achieved after considerable analysis and confirmed by test. It is shown approximately in Fig. 3. One might say that much of the steel reinforcement about the window was required because the window was thick compared with the basic hull. The hull was, in fact, thickened from 1.33 inches to 4 inches. Then the faired reinforcement was required to be of large diameter to lower discontinuity stresses. Actually, the situation is not this simple. The force system applied to the shell by the window creates a large meridional bending moment causing substantial stresses in the steel at the window seat. Thus some reinforcement is required whatever the window thickness and the design of plexiglas window and shell reinforcement have some independent criteria.

Though the design of the window frame or shell reinforcement is a challenging subject, this paper is devoted to the window itself, the previous paragraph being a digression for background.

The *ALVIN* observation windows are shown in (Fig. 2). They were manufactured from Plexiglas monolithic plate cast by Rohm and Haas. Properties reported by the manufacturer are as follows:

Young's Modulus (Tension or Compression)	450,000 psi + 30,000 psi
Poisson's Ratio	0.35
Tensile Strength	10,500 psi
Compression Yield Strength	18,000 psi

A total of twelve windows (fig. 2) have been manufactured and tested. A smaller window, two inches in inside diameter is located in the hatch. Two of these were made, one for each of the two hulls tested.

A summary of the test procedures performed with the *ALVIN* windows is presented below, followed by detailed discussion.

Test No. 1. A .2867 scale model hemisphere containing one window and reinforcement was tested to 1500 psi. The window was strain gaged. Reported in Ref. (5). No leakage was observed.

Test No. 2. Pressure Hull No. 1, of 3 manufactured, was pressure tested once to 1500 psi with windows lapped into their seats. Finish of the steel seat was 30 microinches rms and the window approximately 60 rms. Lapping compound was not recorded. No strain gage data from windows was recorded. Reported in Ref. (6). Minor low pressure leakage due to lack of rubber gasket.

Test No. 3 Pressure Hull No. 1 with windows was pressurized to 2500 psi 16 times, to 3300 psi 16 times, 2700 psi 500 times, and 4300 psi once. One window was strain gaged during the initial 2500 psi and 3300 psi tests and data recorded. The temperature during this phase was about 75° F. The pressure tank failed catastrophically at 4300 psi with Hull No. 1 inside. The hatch was blown off but the windows were undamaged and tight. No window leakage was observed during any of the tests. Report Ref. (7).

Test No. 4. Pressure Hull No. 2 (currently being used in ALVIN) was tested to 3300 psi. Four new windows were made for this hull. No strain gages were mounted on the windows. Reported in Ref. (8). No. leakage.

Test No. 5. In the course of operations during 1964, the windows of Hull No. 2 suffered some deterioration. Window No. 3 (See Table 1 for orientation) was crazed and chipped on the edges. Window No. 2 contained an optical flaw, probably in manufacture. Window No. 1 was crazed. The crazing was minor and believed due to chemical attack of an unsuitable cleaner. The chipped edges were due to insufficient radius. It was decided to run destructive tests, if possible, on the damaged windows and four new windows were made for Hull No. 2.

Old window No. 3 from Hull No. 2 was strain gaged in accordance with Fig. 7 and instrumented to measure deflection. A test jig was made to simulate the window seat (Fig. 5). Pressure was run up to 11,500 psi, the operating limit of the tank used. Temperature throughout the test was 32 - 38°F.

Old window No. 1 from Hull No. 1 was pressurized to 11,500 psi without instrumentation, or temperature control.

The four new windows were proof tested to 5000 psi with deflection instrumentation.

In this group of tests the fit of each window in the hull and in the test jig was measured carefully and the windows were not lapped into their seats. Reported in Ref. (9). No. leakage was observed

Test No. 6. The fit of a window to its seat was measured at 70°F . the window as then cooled to 29°F. The fit was again measured, there was no change in diametral clearance.

Reduction of Strain Data

Two principal strains in the plane of the window inside or outside surface were measured. The principal stresses at a gage location can be derived as follows from a knowledge of the principal strains and a principal stress normal to the surface. At the outside surface of the window this normal stress is the applied hydrostatic pressure and at the inside surface it is zero.

The classic triaxial stress-strain relationships (Ref. 4) are:

1) $$\sigma_x = \frac{E}{(1+\nu)\ (1-2\nu)} \left| (1-\nu)\ \varepsilon_x + \nu\ (\varepsilon_y + \varepsilon_z) \right|$$

2) $$\sigma_y = \frac{E}{(1+\nu)\ (1-2\nu)} \left| (1-\nu)\ \varepsilon_y + \nu\ (\varepsilon_z + \varepsilon_x) \right|$$

3) $$\sigma_z \quad \frac{E}{(1+\nu)\ (1-2\nu)} \left| (1-\nu)\ \varepsilon_z + \nu\ (\varepsilon_x + \varepsilon_y) \right|$$

E = Young's Modulus of Elasticity
ν = Poisson's Ratio

Solution of equation 3 for E_z and substitution in equations 1 and 2 gives:

$$\sigma_x = \frac{E}{1-\nu^2} (\varepsilon_x + \nu\varepsilon_y) + \frac{\nu}{1-\nu} \sigma_z$$

$$\sigma_y = \frac{E}{1-\nu 2} (\varepsilon_y + \nu\varepsilon_x) + \frac{\nu}{1-\nu} \sigma_z$$

$$\sigma_z = -\rho$$

For outside surface, P = hydrostatic applied pressure.
For inside surface, P = 0.

Presentation of Results of Test

The results of tests 3 and 5 reduced as above are presented in Fig. 4, 8, and 9. The windows were lapped into their seats for tests 1 and 3. The temperature of the window for tests 1, 2 and 3 (3300 psi) was estimated at 75° F. and for test 4 at 40° F. These tests were performed at Southwest Research Institute under the direction of Applied Science Division, Litton Systems, and WHOI.

Tests 5 were conducted in March 1965 by Ocean Research Equipment Inc., of Falmouth, Massachusetts under the direction of WHOI. Principal results are reported in (Ref. 9). They are summarized and supplemented herein. Six windows were tested in the program, two of the original windows which had been in Hull No. 2 since October 1963 and four new windows made in accordance with Fig. 2.

One objective of the tests was to determine whether or not lapping of the windows into their seats was necessary, the other was a destructive test if possible with available facilities.

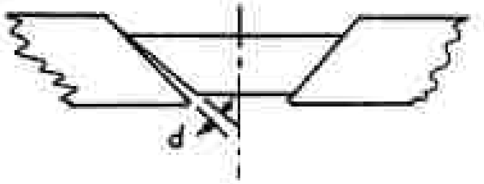
A previously used window (No. 3) which was crazed on the exterior surface and chipped on the edges was instrumented with six 90° rosette strain gages inside and out, as well as with a displacement transducer. This test was conducted at low temperature (35° F) and the window pressurized to 11,500 psi, the operating limit of the tank. Near this pressure measurable creep was observed and measured. Another previously used window (No. 1) was tested to the same pressure at room temperature, uninstrumented. Proof tests to 5000 psi were conducted with the four new windows for *ALVIN* measuring window displacement only.

Window No. 3 was selected to have a poor fit in the test jig seat, a diametral clearance of .030 inches (See Table 1). No. 1 window had a good fit, .004 inches. The four new windows had fits varying from - .006 to .044 inches (Table 1).

The results are presented in (Fig. 8-12). They consist of stresses, deflections, and creep.

Table 1 Fit of Windows for Test 5

The fit of a window in either its seat in the pressure hull (fig. 3) or the test jig (fig. 5) was measured as shown in the sketch below, as the diametral inside clearance, d. A feeler gage was inserted into the clearance gap from the inside a distance of ½ inch. A Diametral clearance of 0.001 inches represents an angle of 0.69 minutes. For test, the windows were positioned



so that equal clearance existed all around the periphery.

Diametral Clearance Inside

Window	*Hull No. 2 Window Seat*	*Test Jig*
Old Front No. 1	.012 inches	.004
Old Port No. 2	.004	.024
Old Stbd No. 3	.003	.030
Old Bottom No. 4	.0015	.032
New Front No. 1	.0015	-.0065
New Port No. 2	.024	.044
New Stbd No. 3	.012	.039
New Bottom No. 4	.012	.043

The included angle of the Hull No. 2 window seats were as follows:

Front No. 1	89° 3.3'	Average of 3 measurements
Port No. 2	89°21.7'	"
Stbd. No. 3	89°26.7'	"
Bottom No. 4	89°26.7'	"

Discussion of Results

Referring to Figures 9 and 12, substantial creep was first observed at a pressure of 10,000 psi. The stress at the center of the window at this pressure was 14,200 psi. Above this pressure, the strain measurements cannot be easily translated into stress so that the stress indicated for gages 1T and 2T is indicated by a dotted line. If 10,000 psi is taken as the pressure at which significant plastic flow takes place and plotted on Figure 1, excellent agreement with Piccard's curve is found.

The fact that no permanent damage to the material at the gage locations was observed on either of the windows which were tested to 11,500 psi ("old" windows No. 1 and 3) suggest that the design is very conservative for 3000 psi. Damage was observed, however, on the inner side of these two specimens, where the window material was forced past the conical seating surface. Window #3 sustained a 1/16" deep crack around the periphery. Window #1 which fit closely to its seat sustained a deeper crack 3/32" also running all around the periphery. While the displacements of the new windows (Figure 11) were insufficient to cause this damage at 5000 psi, a suggested design change would be to extend the conical seating surface a greater distance beyond the inner surface of the window, or perhaps, since the design seems so conservative, to thin the window somewhat from the inside surface.

The measured diametral clearance at the inner surface of "new" windows No. 1, 2, 3, and 4, relative to the test seat was -0.0006", +0.044", +0.039", and 0.043" respectively. (See Table 1) The extremely good reproducibility of the displacements of these windows (Figure 11) suggests that variation of fit of this magnitude is unimportant. The lesser displacement of the old window may be the result of a higher modulus and higher value of ν.

At pressure above 10,000 psi, significant creep was observed on window No. 3 (Figure 17). It is recommended that future tests include creep measurements over a period of several hours. On the basis of extrapolation of the present data, 11,500 psi may represent the failure pressure of the window whereas at 10,000 psi, it can be expected that the window will remain intact for more than 12 hours.

Figure 4 presents the results of strain gaged tests 3 at SWRI. It is noted the full seating of the window did not take place until 2500 psi at which pressure the strain-pressure relationship at the inside surface of the window became linear. Linearity at other locations was established between 1000 and 1500 psi.

Figure 6 notes comparative results of tests 1, 3, and 5, and presents the ratio of stress per unit pressure after linearity was established. Thus the data of Figure 6 is only applicable above 1000-2500 psi depending upon location. No data from tests 3 for inside gages was presented here because linearity was not established during the test.

An external rubber gasket was used in all cases except tests 1 & 2. No leakage was observed except in test 2 when the gasket was omitted. Therefore, such a gasket is required.

There is very good agreement in Figure 6 between tests 3 and 5 on the outside surface in spite of differences in conditions that could introduce discrepancies. Test 3 and 5 were run with different windows. The modulus of elasticity and Poisson's ratio were assumed constant with temperature in the absence of information to the contrary. This may have introduced error. Test 3 was run with a real pressure hull under pressure whereas test 5 used a test jig which did not simulate strain of the window seat. In the case of the real hull at 3300 psi, a circumferential compressive strain of .0013 at the outside and .0017 at the inside were measured at the window seat. The mean window strain across the outside surface was measured at .0050. Since there is only a factor of 4 difference, a noticeable effect on the window stresses caused by hull strain might be expected. Probably the window is squeezed outward instead. If this is the case then the window displacement presented in Figure 11 would be larger by 3% than those expected of the windows in the real hull. It is concluded that the test seat does provide sufficient similarity to the real hull for interpretable and useful data to result. <u>It is concluded on the basis of tests reported herein and service experience that plexiglas windows can be designed with high confidence</u>.

The low values of stress experienced in the model test which did simulate hull strains are unexplained. Possibly a difference in plexiglas properties or scale effect was present.

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The following persons participated in the work discussed in this report and their contribution is gratefully acknowledged. Arnold Sharp of WHOI, David H. Frantz and Michael D. Pearlman of Ocean Research Equipment, Inc., Edward Briggs of Southwest Research Institute, Dr. Joseph B. Walsh of WHOI and MIT, and Harold E. Froehlich of Programmed and Remote Sustems, Inc.

Appreciation is expressed to Ray Loughman of Electric Boat Div. GDC for permission to report the observations noted in appendix I.

In spite of the satisfactory performance of plexiglas windows in deep submersibles when subject to high hydrostatic pressures, it is important to note that the material is brittle and of low strength when compared with the steel used in a pressure hull. This implies that while the steel hull can stand the impact of a substantial shock pulse or collision, the plexiglas windows cannot. An incident in the experience of the submarine *ASHERAH* is of interest in this area. She is a submarine with a design operating depth of 600 ft. and was designed and built by Electric Boat Division, GDC. for the use of the University of Pennsylvania. She displaces 4 tons and contains two windows shown in Figure 13. They were of plexiglas, not stress relieved. While operating off the coast of Turkey in 1964, *ASHERAH* ran head-on into a coral head at moderate speed at a depth of 20 ft. One window was damaged

It was gouged locally (Fig. 13) to a depth of 1/16 inch. The surface of the gouged region was covered with a mixture of coral and plexiglas filings. A crack which evidently started from the impact region propagated in a plane 45 degrees to the window surface. The crack broke through the surface on the side nearest impact and for about 2 inches on the inside surface. The crack stopped within ½ inch of the surface on the other side. Flaking off on the outside edge occurred. An unknown amount of leakage occurred, but the vehicle surfaced safely without further damage. There was a small displacement, about 1/32", where the crack broke through the surface, indicating relief of residual stress.

This failure is a reminder that plexiglas has low impact and low tensile and compressive strength. The *ASHERAH* window had a diameter to thickness ratio of 3 whereas *ALVIN* has 1.43 indicating that the *ASHERAH* window as a uniformly loaded plate is subject to 4.6 times as much bending stress as the *ALVIN* window at a given pressure. However, the nature of the *ASHERAH* crack propagation does not indicate evidence of the effect of bending stress as the crack was arrested before breakthrough over most of the tension or inner surface.

On the other hand the *ASHERAH* window failed at low hydrostatic pressure. It is possible that the plexiglas could behave as has been shown (Ref. 10) with glass spheres tested at depth under explosive loading, i.e. have greater impact resistance at deeper depths.

In summary, it may be that window impact strength is independent of geometry but possibly depth dependent. In any case it is low. Protective bars have been installed over the bottom window of *ALVIN* for this reason. Protection also might be afforded by a strengthened glass cover to distribute the load.

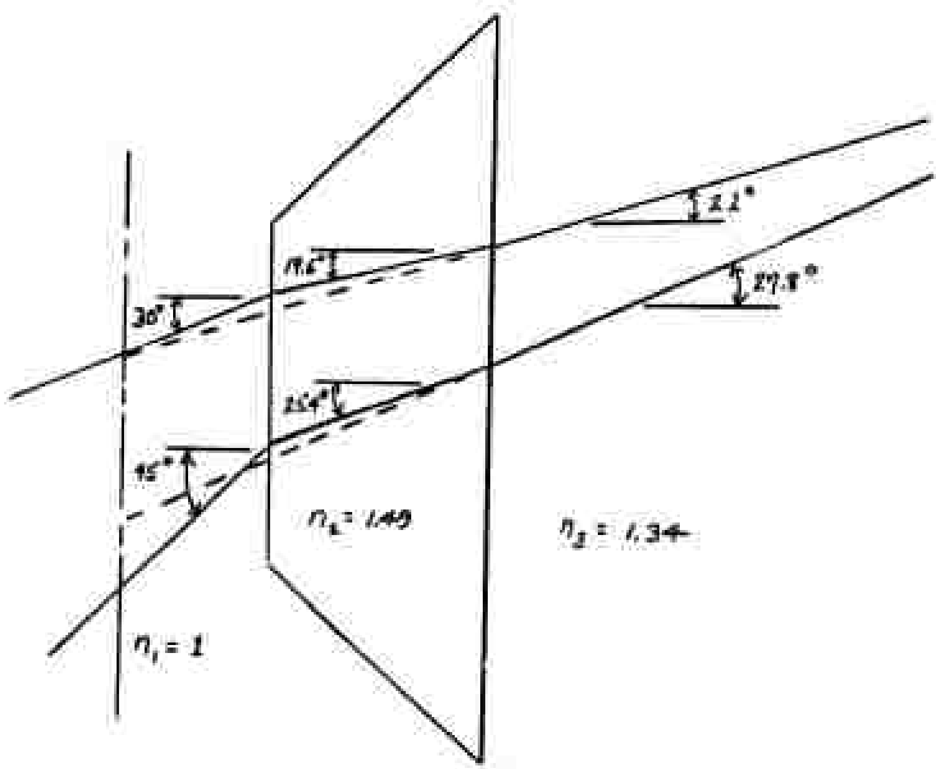
Service experience with the *ALVIN* windows since July 1964 has resulted in a number of observations.

(1) With clearance space between the window and its seat at the inside at low pressure there has been an accumulation of condensation of water vapor, perspiration, and dirt causing minor corrosion of the window seat. This has been corrected by regular cleaning and liberal application of Lubri-plate. It is noted, however, that one window tested (Table I) had a small initial gap on the outside. This presents a possible method of elimating the problem but on the basis of available data considered unwise because of possible leakage.

(2) The use of cleaners which will craze the plexiglas must be avoided. Shallow crazing can be polished off without structural damage but care must be taken to avoid optical distortion.

(3) Window Optics

There is considerable optical distortion when observing with the eye or when taking photographs through the 3½ inch thick plane surface window. As is evident from the light ray diagram below the major distortion is due to the air-plexiglas interface, so that thinning the window would not alter the optics substantially.



The indices of refraction relative to air of several media are tabulated below:

Plexiglas G	1.49
Fused Quartz	1.47-1.57
Glass	1.53-1.69
Pure Water Sodium Light 20°C	1.333
1.035 Sp.gr. NACL Agueous Solution	1.34

On the basis of these indices, the use of quartz or glass would not provide an optical improvement over plexiglas.

For single eye observation or camera use, a spheiically machined plexiglas window would decrease distortion and increase the field of view above the 70° now available. However, it is considered important to be able to use both eyes when observing for periods of hours at a time. With this requirement it appears necessary to use optical components in addition to the window to achieve the water air correction and improvement in the field of view.

Appendix III

Notes on the Manufacture and Maintenance of Plexiglas Windows.

Manufacture

The windows that were manufactured for Hull No. 1, tests No. 2 and 3, included both annealed and not annealed windows. Those used in test 2 were not annealed. For test 3, three of these windows were annealed and one left not annealed. The four windows used with hull No. 2 through 1964 were all annealed. The new windows installed in Hull No. 2 in 1965 were all annealed and were manufactured to the following specifications and figure (2) by Atkins and Merrill Inc., of Marlboro, Massachusetts. A total of 12 windows were manufactured all told.

1. Machine to rough dimensions.
2. Anneal at 195°F. for eight hours.
3. Cool in oven at rate of 5°F per hour to 150°F.
4. Remove from oven, wrap in insulating blanket, and allow to cool to room temperature.
5. Finish machine to dimensions shown on drawing.

While tests did not indicate a difference in strength between annealed and not annealed windows, significant distortion during rough machining was found which made it important to anneal in accordance with the above procedure.

Maintenance

The following procedures are used in caring for the *ALVIN* windows.

1. Cleaning - Basic cleaning operation is to wash windows with non-abrasive soap or detergent and water. A soft grit-free cloth, sponge or chamois may be used. In removing caked dirt or mud, use care to prevent dirt from scratching window. Dry with clean damp chamois or soft cloth. Hard rough cloths will scratch Plexiglas and should not be used.

   Grease and oil may be removed using kerosene or white (not aviation or ethyl) gasoline. Washing with soap and water should follow this operation.

   Do not use solvents such as acetone, benzene, carbon tetrachloride, cleaning fluid or lacquer thinner, since they attack the Plexiglas surface. Alcohol solutions also may harm the window surface.

2. Hand Polishing - Minor scratches can be removed by hand polishing using a fine abrasive liquid or paste polish. DuPont No. 7 Auto Polish and Cleaner has been tested and appears to do an excellent job. Other similar products (Johnson's Carnu, Simoniz Kleener) should work equally well.

When removing scratches, apply the polish with a small pad of flannel or other soft cloth. Use a circular motion or a stright back and forth motion parallel to the scratch to be removed. Avoid excessive rubbing at one spot. Several applications may be necessary to remove deeper scratches. When finished, window should be rinsed free of polishing compound.

3. <u>Waxing</u> - After washing, Plexiglas surfaces may be waxed with a good grade of commercial wax (DuPont Auto Wax, Johnson's Cream Wax, Johnson's Paste Wax). Apply wax in a thin even coat, and bring to a high lustre by rubbing lightly with a dry soft cloth.

   Waxing will improve appearance by filling in minor scratches and will help prevent further scratching.

4. <u>Storage</u> - When not installed in the vehicle, windows should be carefully wrapped in soft cloth or packing material and stored in individual boxes or cartons.

BIBLIOGRAPHY

1. Beebe, William "Half Mile Down" Cadmus, 1934.

2. Barton, Otis, Appendix of "Half Mile Down", Cadmus, 1934.

3. Piccard, Auguste, "Au Fond Des Mers En Bathyscaphe" ARTHAUD, 1954, p.228

4. A. E. H. Love, "The Mathematical Theory of Elasticity, Dover 1944.

5. "Experimental Stress Analysis of a Model of the ALVIN Hull" by D. J. Bynum and R. C. Dehart, SWRI Report April 1963.

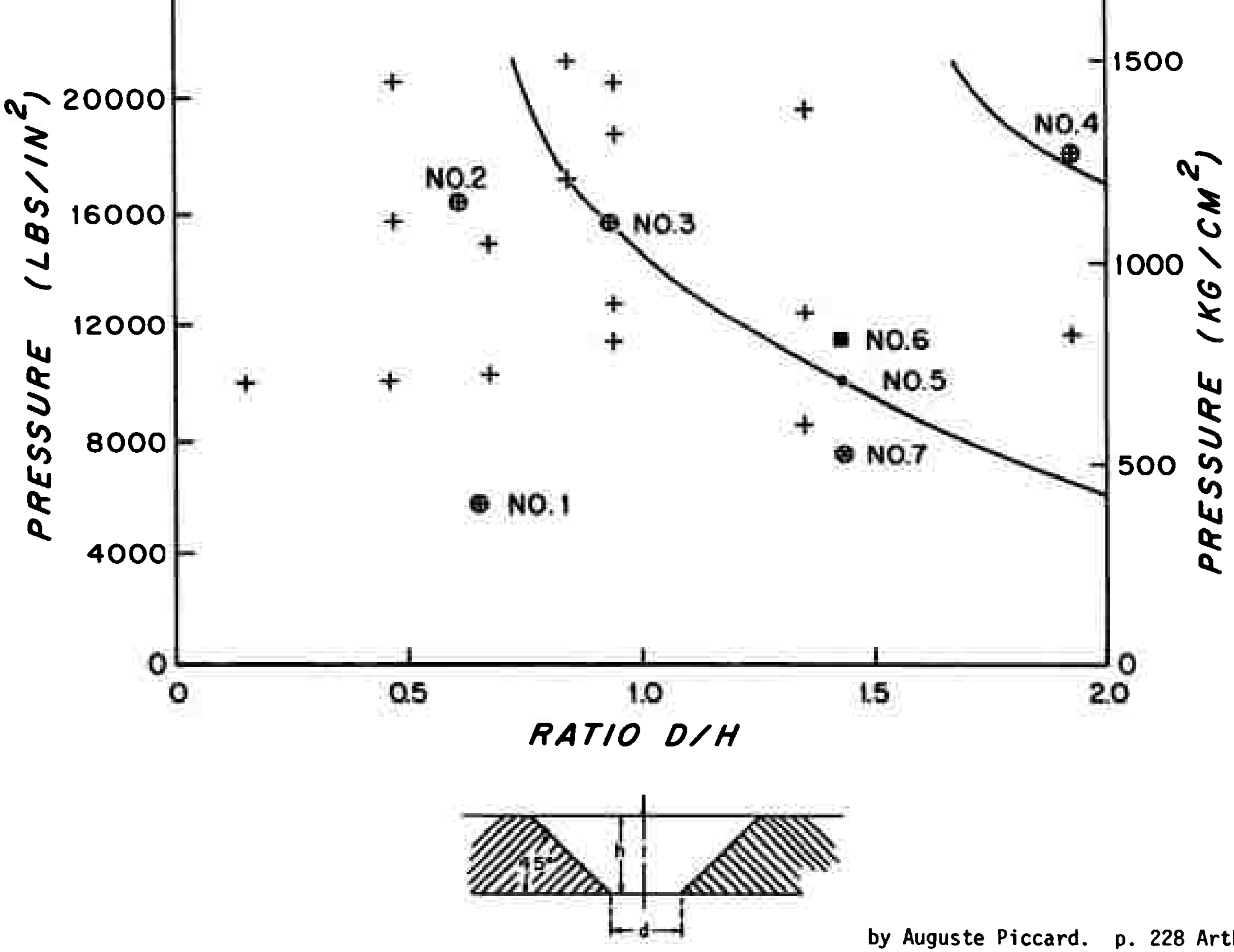
6. "Experimental Stress Analysis and Leak Test for ALVIN Hull Number 1" by E. M. Briggs and R. C. Dehart, SWRI Report April 1963.

7. "Experimental Stress Analysis for ALVIN Hull Number 1" by E. M. Briggs and R. C. Dehart, SWRI Report May 1964.

8. "Experimental Stress Analysis of Hull No. 2" by E. M. Briggs and R. C. Dehart, SWRI Report, June 1964.

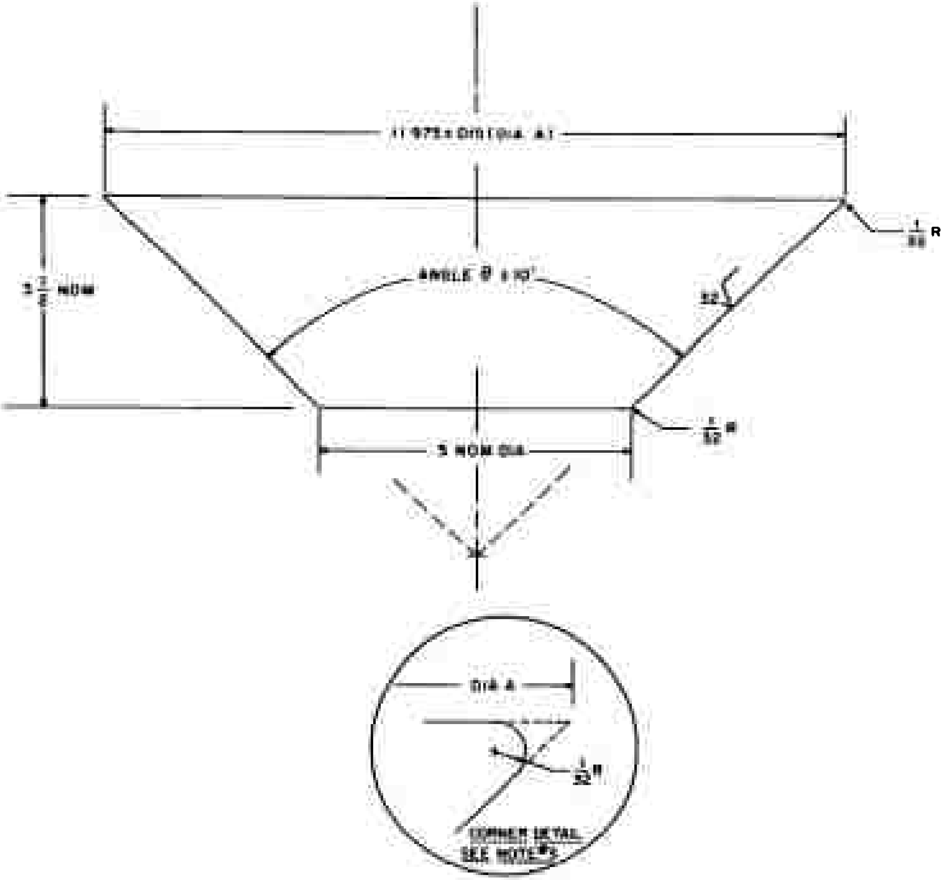
9. "Pressure Tests of Plexiglas Windows of ALVIN Submarine" by Ocean Research Equipment, Inc. ORE Report 04651 April 1965.

10. "The Argument for Glass Submersibles" by H. A. Perry Undersea Technology September 1964.



by Auguste Piccard. p. 228 Arthaud 1954.

1. "Pressure Test of Small Models of Ports" from "Au Fond Des Mers En Bathyscaphe"



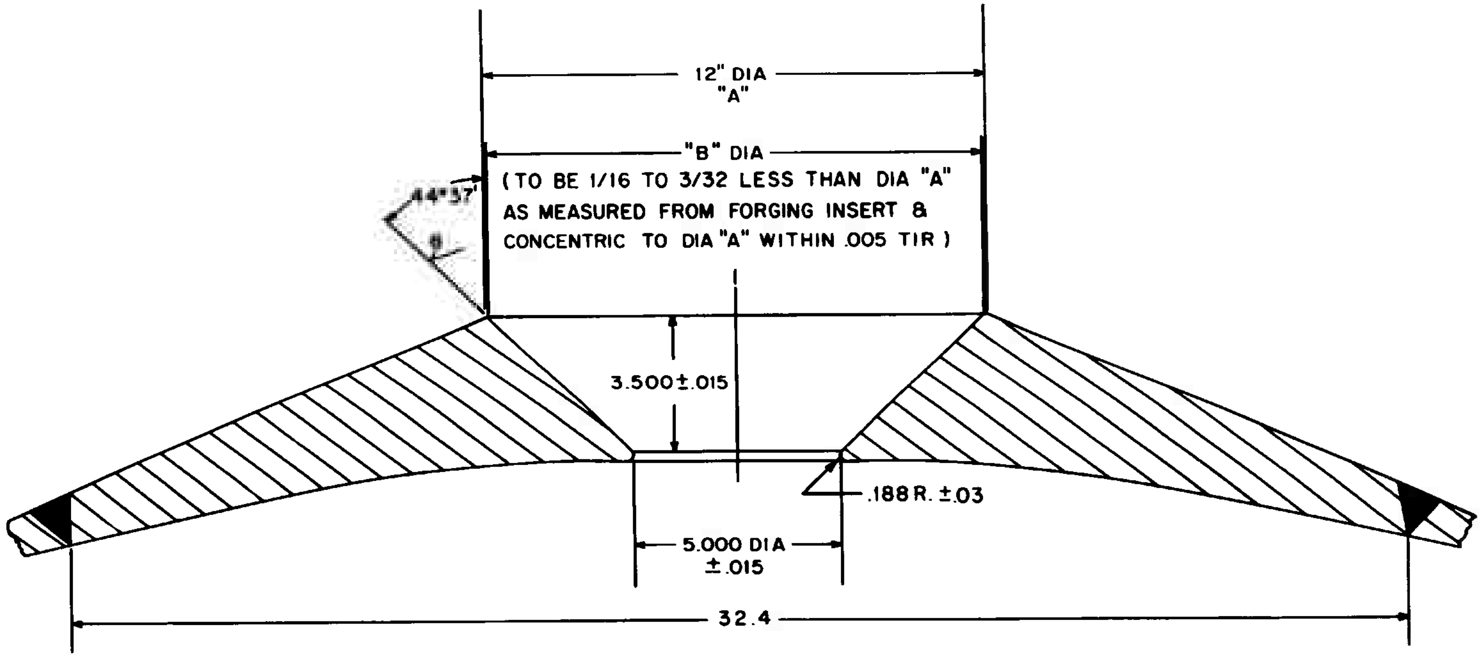
INCLUDED ANGLE θ MEASURED FROM WINDOW SEATS

FRONT	WINDOW	89°
PORT	WINDOW	89° 20'
ST'B'D	WINDOW	89° 25'
BOTTOM	WINDOW	89° 25'

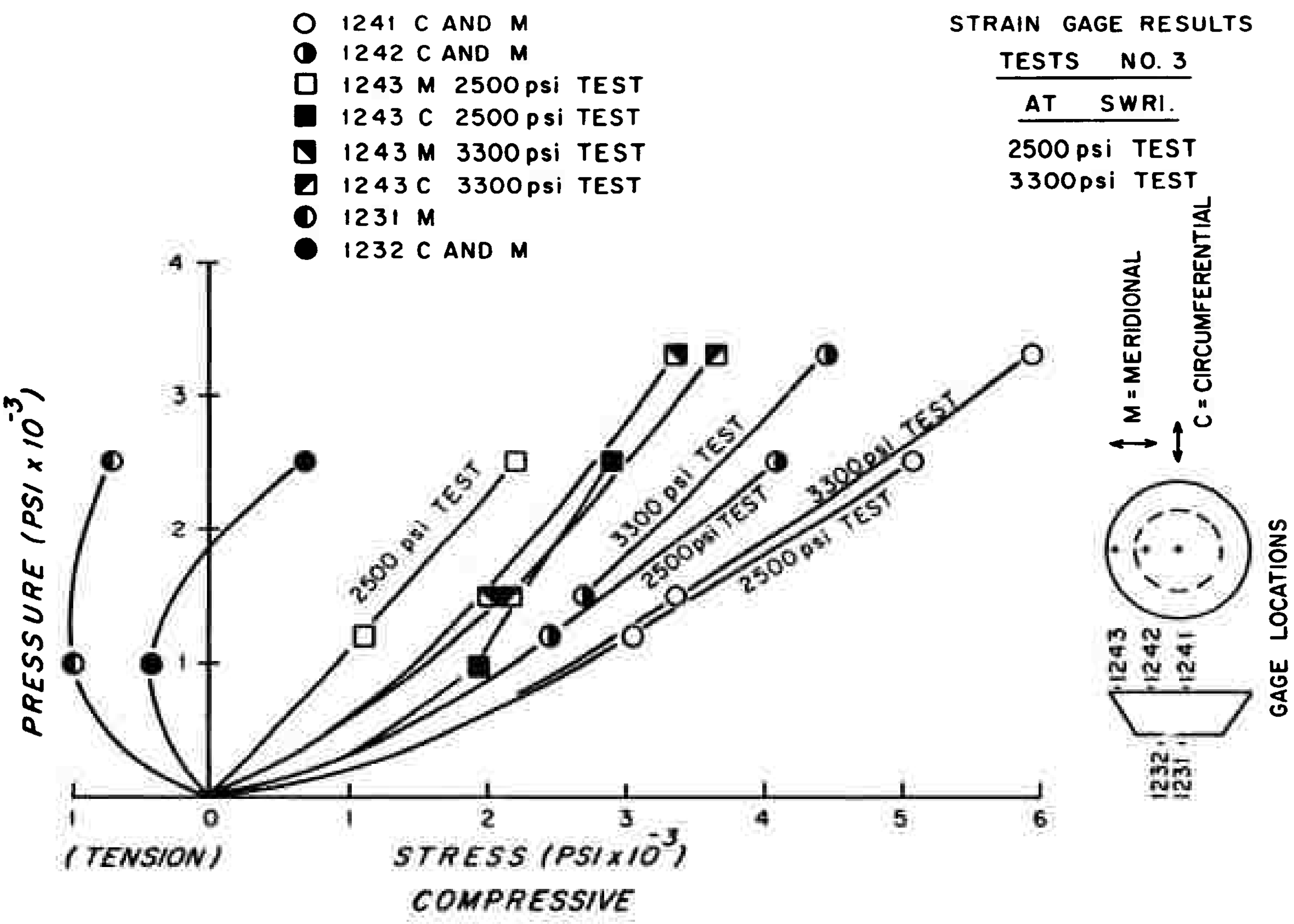
NOTES

1. O.D. (DIAM A) AND THICKNESS SAME FOR ALL WINDOWS.
2. MAKE INCLUDED ANGLE θ TO MATCH SEAT MEASUREMENT OF ABOVE TABLE, ± 10', ONE EACH
3. RADIUS CORNERS AFTER ESTABLISHING SPECIFIED OUTSIDE DIAM. (SEE DETAIL).
4. NO SCATCHES OR DEFECTS PERMITTED ON SURFACES OR WITHIN PLASTIC.
5. MATERIAL: PLEXIGLAS G.
6. FOUR (4) REQUIRED; ONE EACH SEAT MEASUREMENT

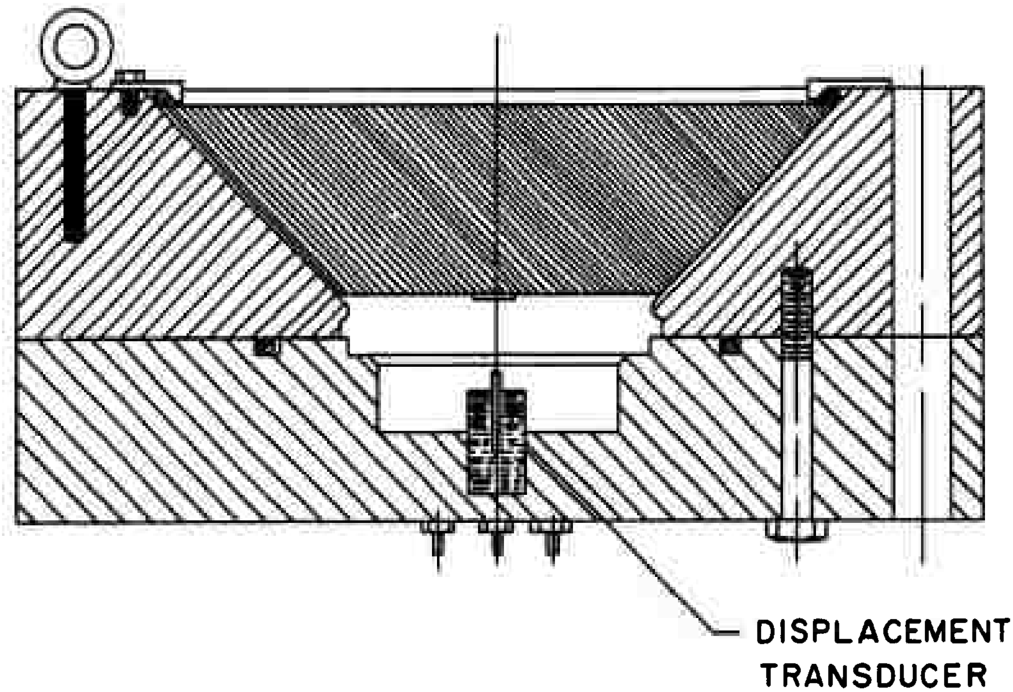
2. "ALVIN Window".



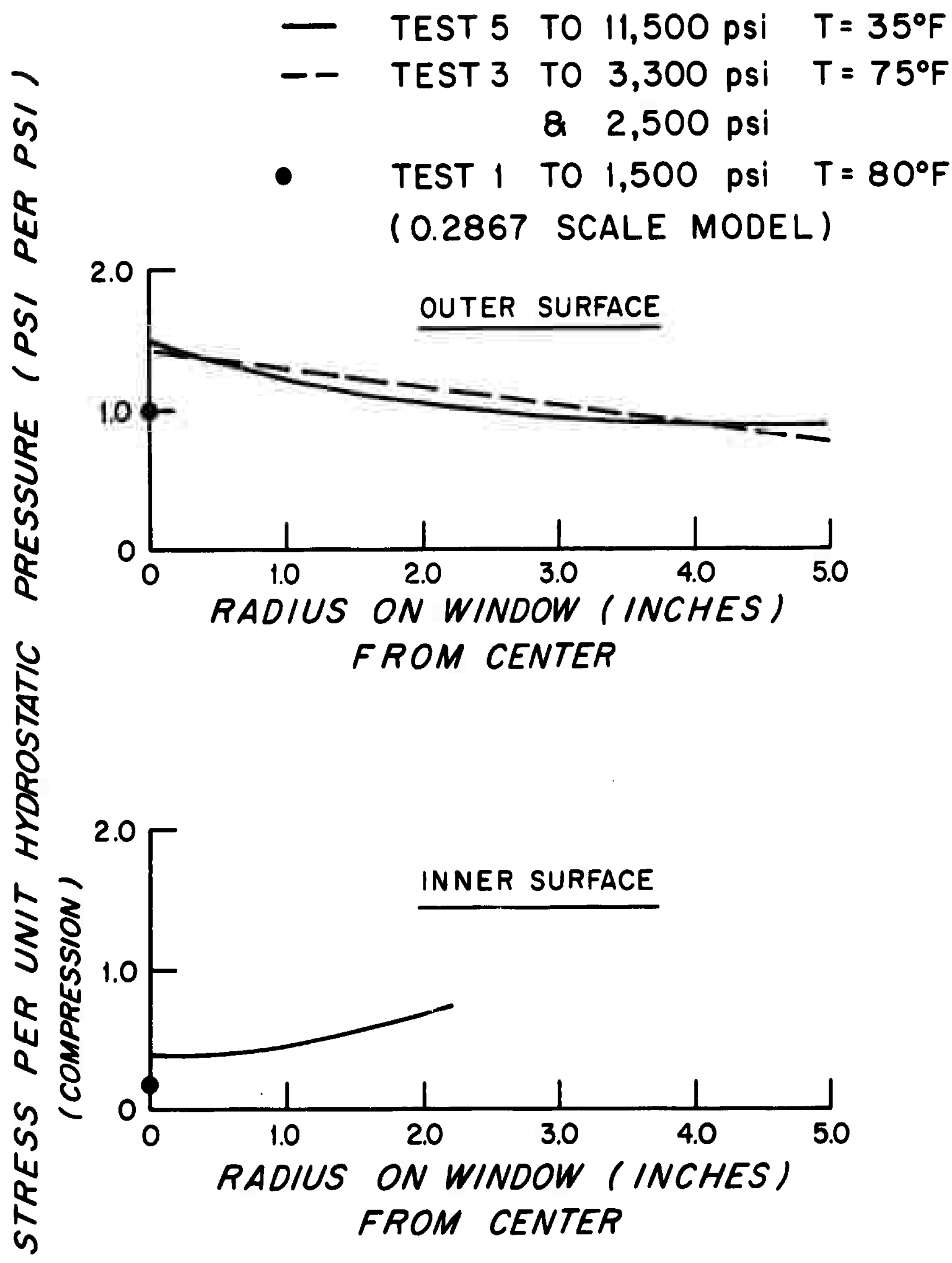
3. "ALVIN Hull reinforcement in way of window".



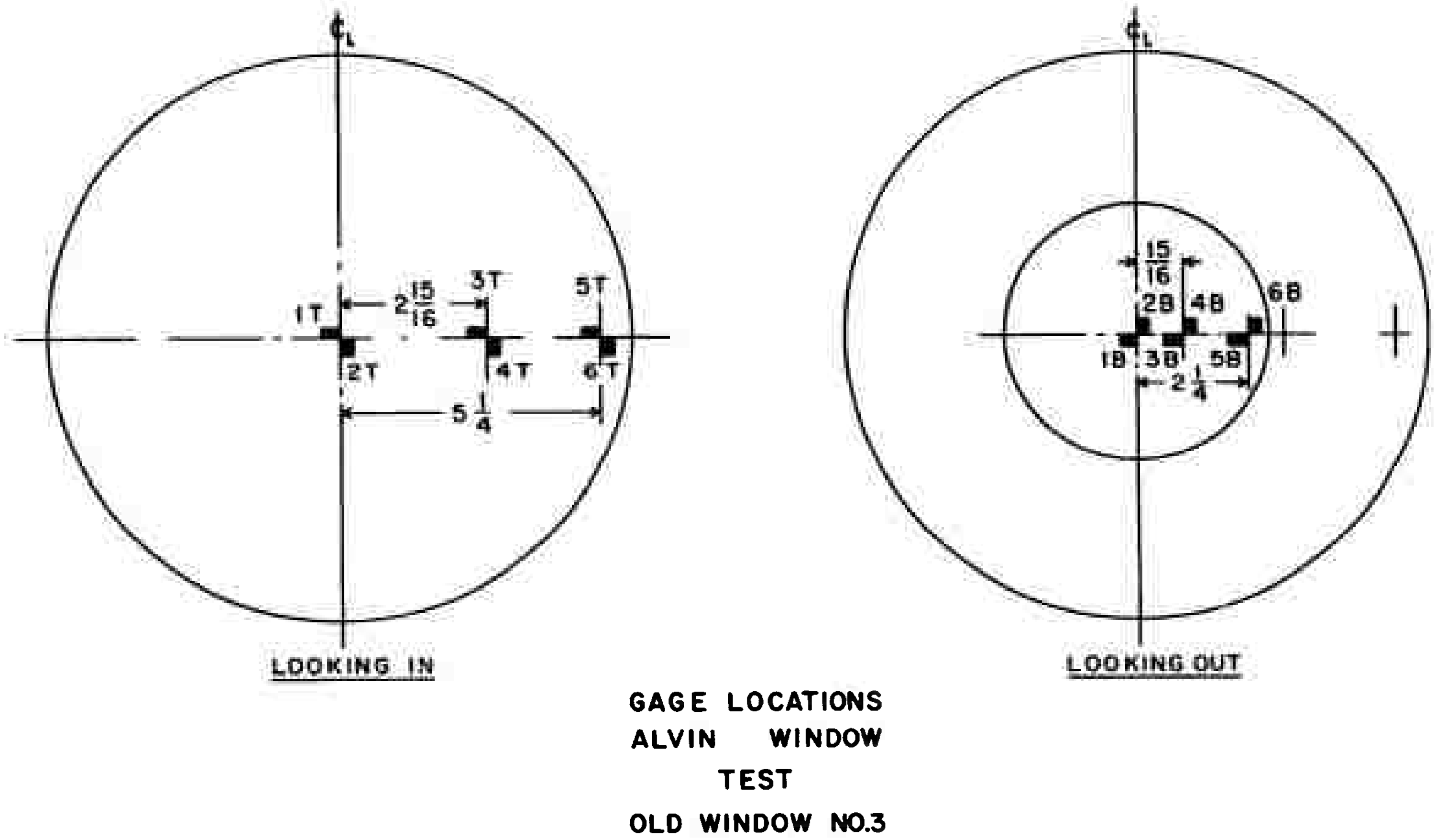
4. Strain Gage Results Tests No. 3 at SWRI.



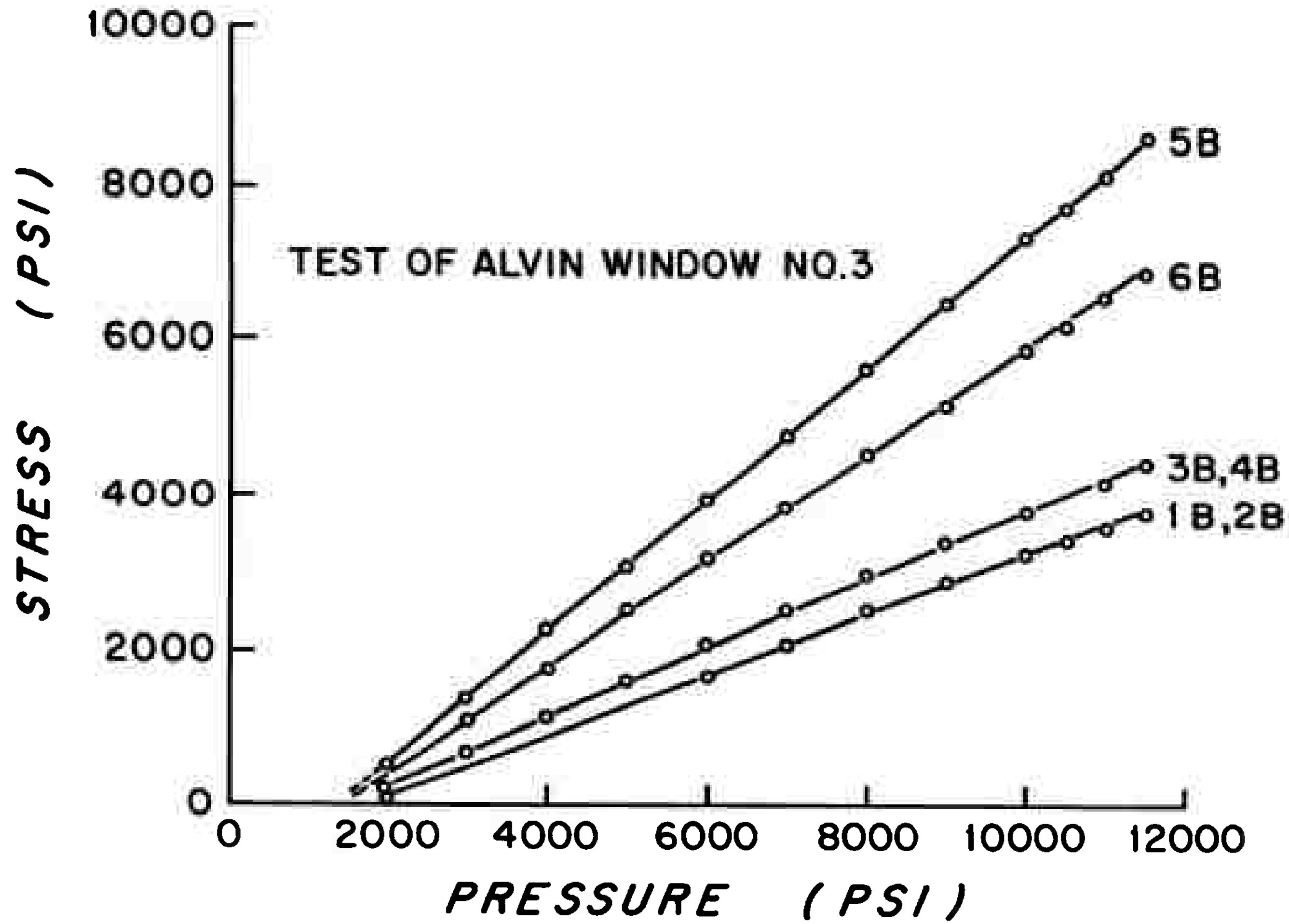
5. Window Test Jig.



6. "Comparison of Results of three Strain Gaged Window Tests".

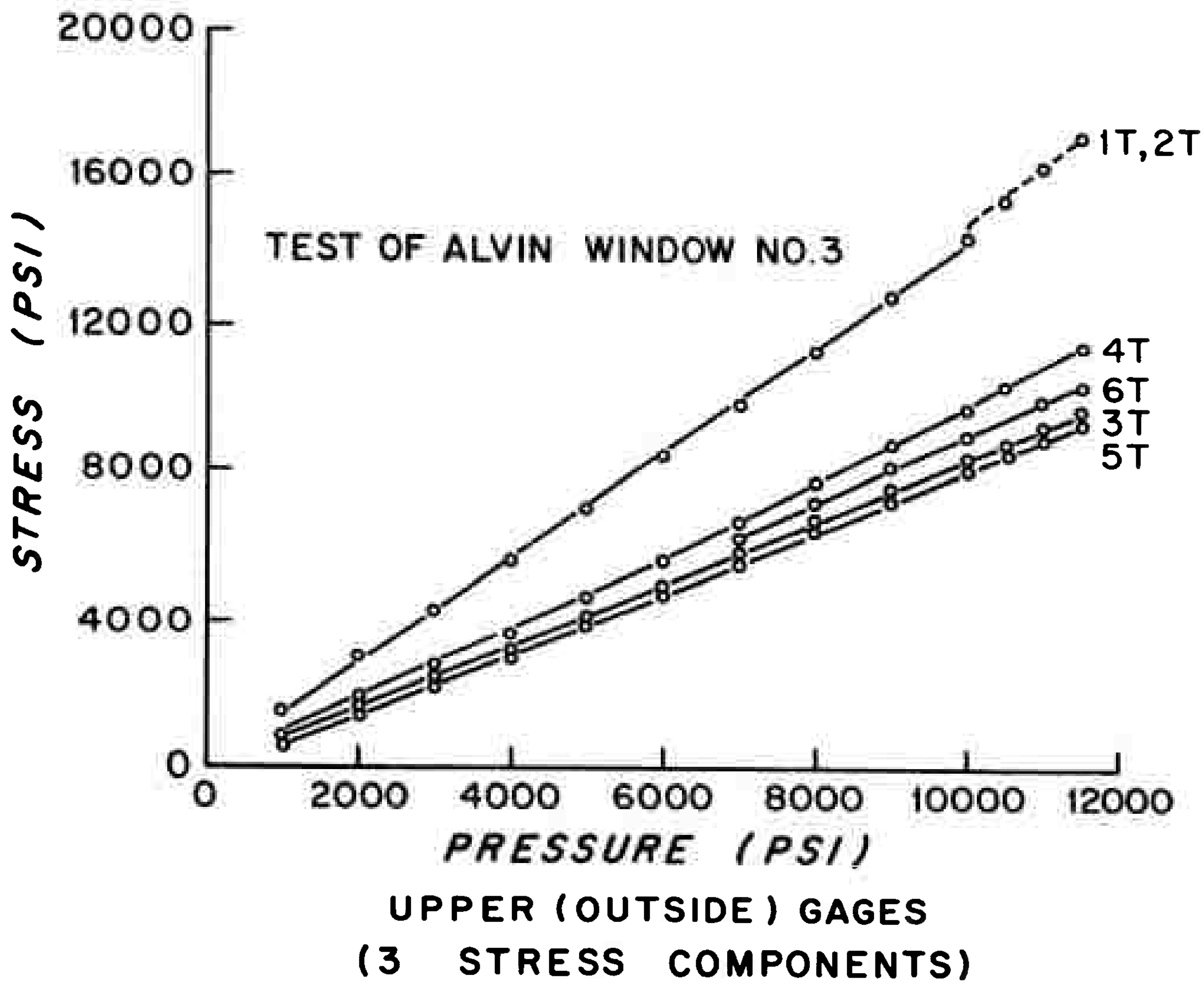


7. Strain Gage Locations Old Window No. 3, Hull No. 2.

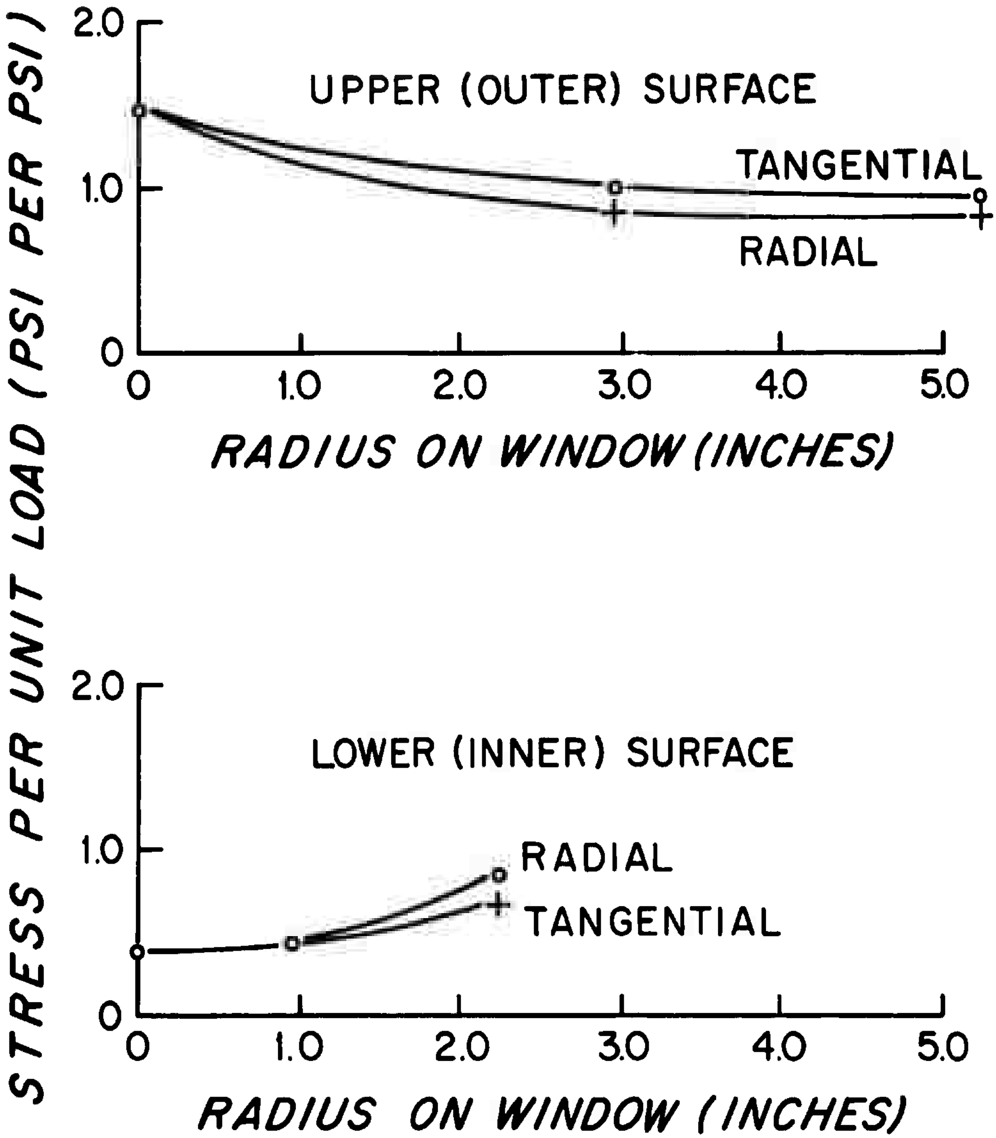


BOTTOM (INSIDE) GAGES
(PLANE STRESS ≈ 3 COMPONENT STRESS)

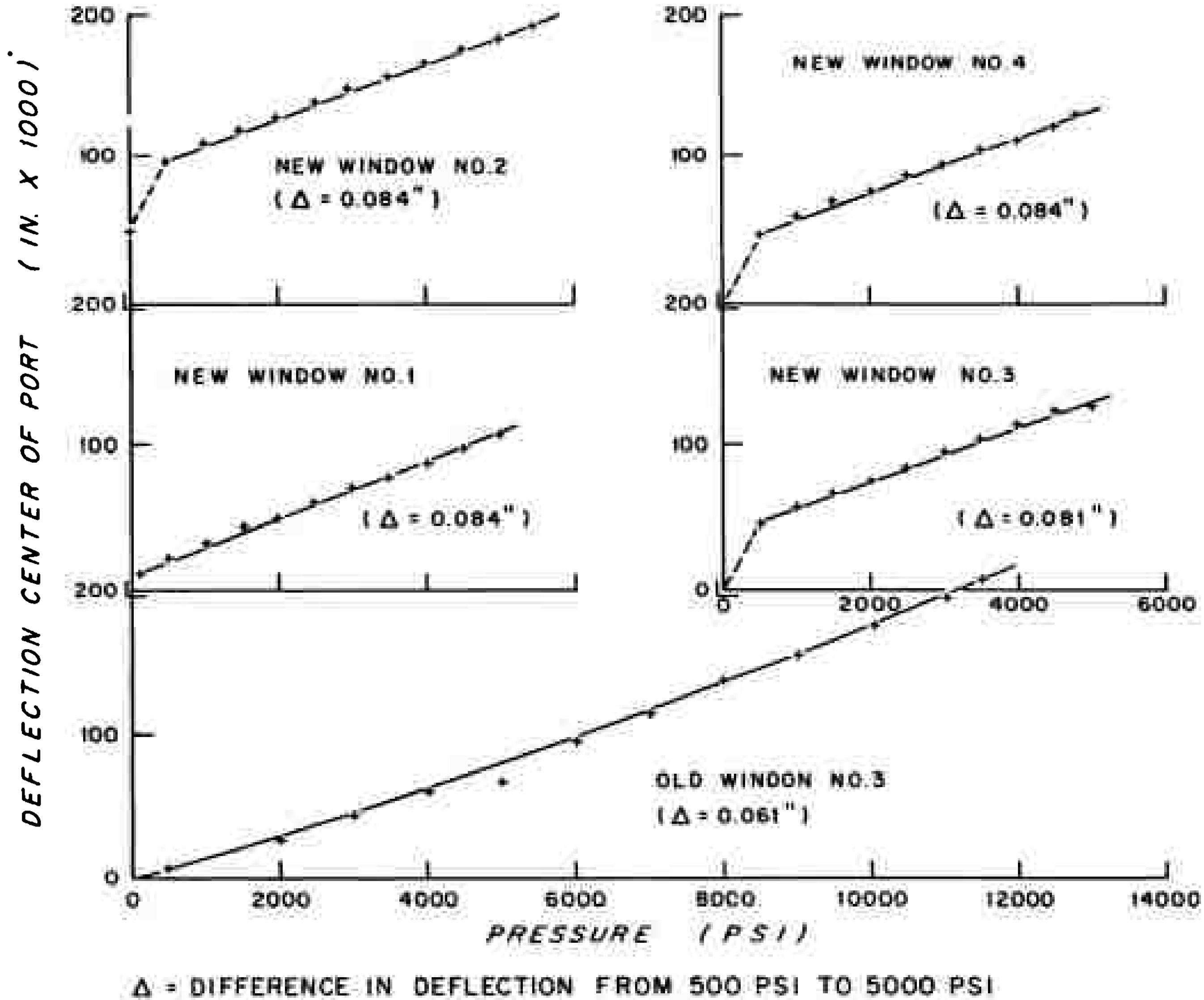
8. ALVIN Window No. 3 test 5 Inside Strain Gages.



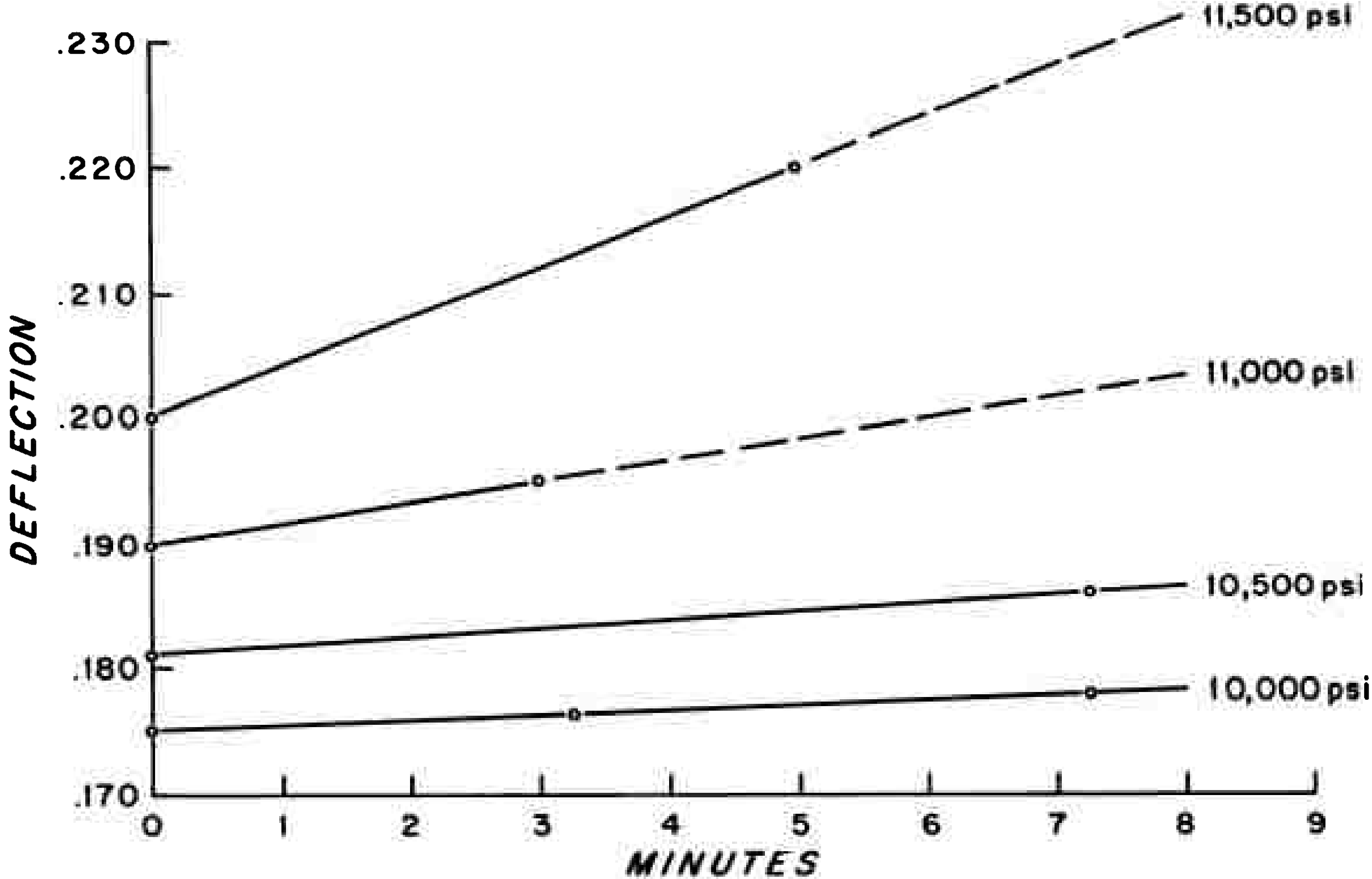
9. ALVIN Window No. 3 test 5 Outside Strain Gages.



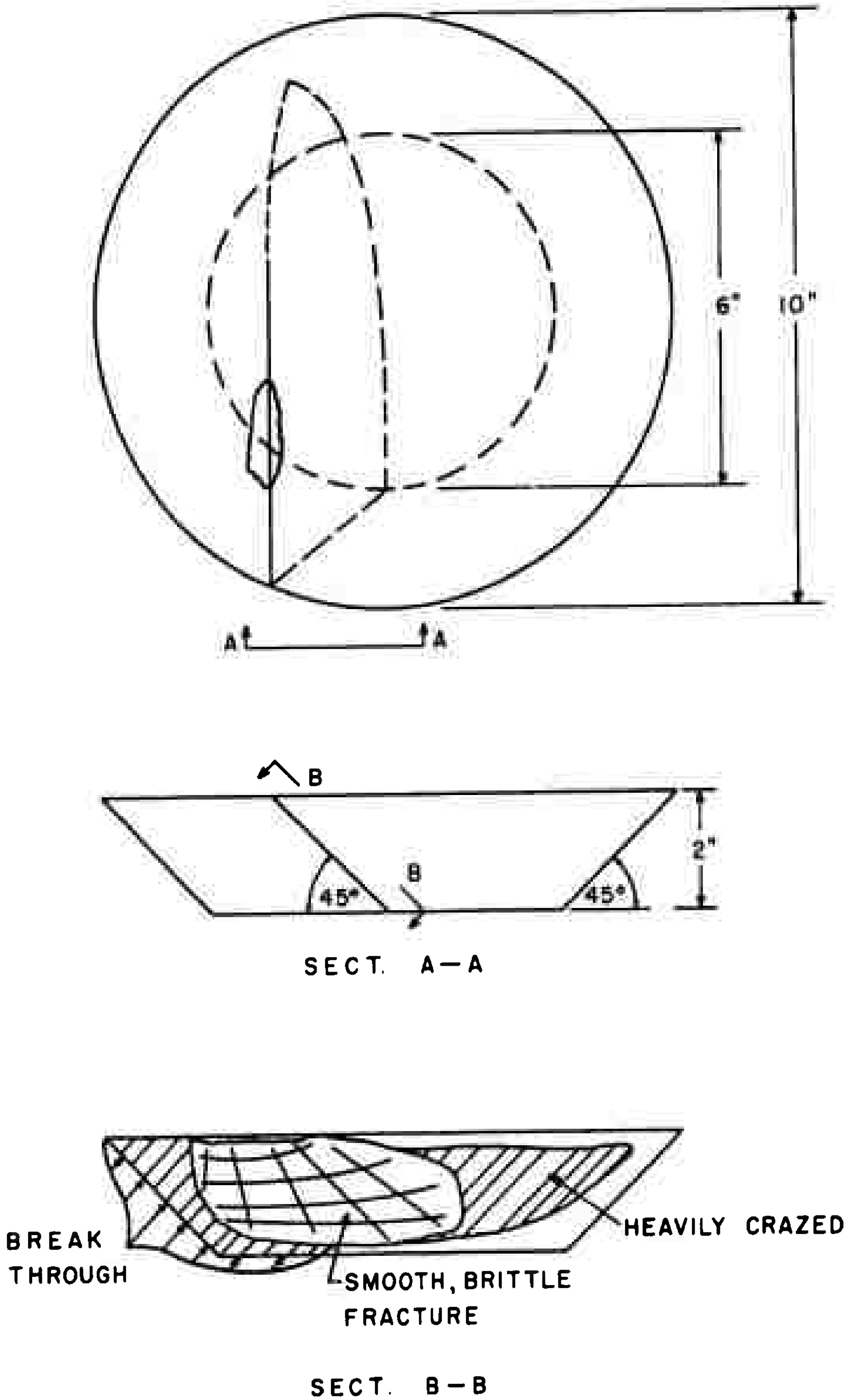
10. ALVIN Window No. 3 test 5 Stress vs Window Radius.



11. ALVIN Window Displacements test 5.



12. ALVIN Window No. 3 Creep measurements.



13. ASHERAH Window Damage.

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4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Technical Report

5. AUTHOR(S) *(Last name, first name, initial)*

James W. Mavor, Jr.

6. REPORT DATE December 1965	7a. TOTAL NO. OF PAGES 30	7b. NO. OF REFS

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13. ABSTRACT

The basis of the design of the *ALVIN* plexiglas windows is presented. The results of several tests of plexiglas windows are presented and discussed. It is concluded that the lapping of windows into their seats is unnecessary and that close fit is also not required. The *ALVIN* windows are conservative in design for an operating depth of 6000 feet. The use of a test window seat which does not simulate the hull strains is satisfactory for window test. It is recommended that the conical window seat be extended inward beyond the window to allow for normal elastic extrusion. Plexiglas windows are susceptible to collision damage due to brittleness and low strength of the material. An external rubber gasket was required to prevent low pressure leakage.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. *ALVIN*						
2. Submarine						
3. Windows						

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